



Research article

Ecological typologies of large areas. An application in the Mediterranean Sea



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ABSTRACT

One approach to identifying and mapping the state of marine biophysical conditions is the identification of large-scale ecological units for which conditions are similar and the strategies of management may also be similar. Because biological processes are difficult to directly record over large areas, abiotic characteristics are used as surrogate parameters. In this work, the Mediterranean Sea was classified into homogeneous spatial areas based on abiotic variables. Eight parameters were selected based on salinity, sea surface temperature, photosynthetically active radiation, sea-wave heights and depth variables. The parameters were gathered in grid points of 0.5° spatial resolution in the open sea and 0.125° in coastal areas. The typologies were obtained by data mining the eight parameters throughout the Mediterranean and combining two clustering techniques: self-organizing maps and the k-means algorithm. The result is a division of the Mediterranean Sea into seven typologies. For these typologies, the classification recognizes differences in temperature, salinity and radiation. In addition, it separates coastal from deep areas. The influence of river discharges and the entrance of water from other seas are also reflected. These results are consistent with the ecological requirements of the five studied seagrasses (*Posidonia oceanica*, *Zostera marina*, *Zostera noltei*, *Cymodocea nodosa*, *Halophila stipulacea*), supporting the suitability of the resulting classification and the proposed methodology. The approach thus provides a tool for the sustainable management of large marine areas and the ability to address not only present threats but also future conditions, such as climate change.

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1. Introduction

The Mediterranean Sea represents only 0.82% of the ocean surface, but with nearly 17,000 known marine species, it is home to 4–18% of global marine biodiversity and 10–48% of endemic species depending on the groups (Coll et al., 2010). Due to the high biodiversity of the Mediterranean, many habitats and species are under protective regimes (Council of the European Commission, 1992; IUCN, 2015; UNEP-MAP-RAC/SPA, 1995), justifying the generation of a network of protected areas as a tool for marine and coastal ecosystems conservation (Rodríguez-Rodríguez et al., 2016). The lack of knowledge regarding species and habitat distribution could, however, compromise the sustainable management of those

connected species as a whole. One approach to reducing this uncertainty is the identification of large-scale ecological units that are more manageable to assist in the management of a biogeographically complex region (Grega et al., 2012; Last et al., 2010). Notarbartolo di Sciara and Agardy (2010a) established that subdividing the Mediterranean into broadly homogeneous subunits would help in priority setting and planning for marine conservation in the region. This division allows the recognition of different parts of the region, where ecological and abiotic conditions are similar and the management strategies could also be similar (Howell, 2010).

The Mediterranean has been traditionally divided into two large subregions (East and West). This division into two ocean basins is, however, too coarse to detect typologies that influence species distribution. In recent years, more detailed classifications of the Mediterranean Sea have appeared to solve this issue (Table 1). Several studies take into account geomorphological and

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Table 1
The most widely used classifications existing in the Mediterranean Sea.

Reference	Divisions	Criteria
Bianchi 2007	1. Alborán Sea 2. Algerian and north Tunisia coasts 3. Southern Tyrrhenian Sea 4. Balearic Sea to Sardinia Sea 5. Gulf of Lions and Ligurian Sea 6. Northern Adriatic Sea 7. Central Adriatic Sea 8. Southern Adriatic Sea 9. Ionian Sea 10. Northern Aegean Sea 11. Southern Aegean Sea 12. Levant Sea 13. Straits of Messina	Biogeographic peculiarities
Spalding et al., 2007	1. Adriatic Sea (30) 2. Aegean Sea (31) 3. Levantine Sea (32) 4. Tunisian Plateau/Gulf of Sidra (33) 5. Ionian Sea (34) 6. Western Mediterranean (35) 7. Alborán Sea (36)	Biogeographic basis (range discontinuities, dominant habitats, geomorphological features, currents, temperatures, etc.) Practical utility (nested system, operating globally) Parsimony
European Commission 2008	1. Western Mediterranean 2. Adriatic Sea 3. Ionian Sea and the Central Mediterranean Sea 4. Aegean-Levantine Sea	
Notarbartolo di Sciara and Agardy 2010b	1. Alborán Sea 2. Algero-Provençal Basin 3. Tyrrhenian Sea 4. Adriatic Sea 5. Ionian Sea 6. Tunisian Plateau/Gulf of Sidra 7. Aegean Sea 8. Levantine Sea 22 regions	Depth profiles Oceanographic and biogeographical differences
Berline et al., 2014		Oceanographic distances (dispersal by ocean circulation) Larval dispersal
Rossi et al., 2014	65 provinces with a larval duration of 30 days and 32 provinces for a larval duration of 60 days	
Gabrie et al., 2012	37 epipelagic regions (level III) 16 bioregions (level II) 5 bioregions (level I)	Statistical analysis
Nieblas et al., 2014	5 subprovinces	Statistical analysis
Reygondeau et al., 2017	12 epipelagic layers	Statistical analysis
Witze 2017	The Ecological Marine Units (EMU) number 9 and 21	Statistical analysis

biogeographic features (Bianchi, 2007; European Commission, 2008; Notarbartolo di Sciara and Agardy, 2010b; Spalding et al., 2007); however, they have found that regional patterns are limited to continuous areas, and areas geographically separated but with similar abiotic conditions cannot be considered to have the same typology. Recent studies have characterized the Mediterranean provinces according to abiotic variables using statistical methods to objectively subdivide the area. Some of these classifications have a clear objective, for example, larval dispersal by oceanic currents (Berline et al., 2014; Rossi et al., 2014), while others are broadly oriented, employing a more complete set of

variables (Gabrie et al., 2012; Nieblas et al., 2014; Reygondeau et al., 2017; Witze, 2017).

These works have included variables related to the abiotic conditions of the water, providing a wider view of the Mediterranean Sea than biogeographic approaches, which have been geographically limited to the definition of regional seas. However, a comprehensive study also considering meteo-oceanographic (hereinafter referred to as met-ocean) variables has not yet been performed. The met-ocean variables (e.g., temperature and sea surface waves) are related to the survival of species, especially floral species that support the whole ecosystem. Changes in their distributions will therefore have cascading effects on the rest of the community. An initial key step for a robust characterization considering climate features is the use of long temporal data series from validated sources. Moreover, not only mean values but also extreme and dispersion information parameters of the variables may better capture the functioning and evolution of the system. This approach would allow the detection of boundaries to the distribution of species in a more reliable way and would allow for better predictions of changes in species ranges under future climate conditions.

Therefore, there is a need for a Mediterranean Sea classification that takes into account these aspects and allows homogeneous areas to be distinguished from an ecological point of view, namely, one that is linked to species distributions. Nevertheless, the scarcity and lack of homogeneity in the biological information makes it difficult to address this perspective. The use of abiotic variables as surrogates of ecological processes has been shown to be advantageous to resolving this issue (Huang et al., 2015; Juanes et al., 2016; Last et al., 2010; Ramos et al., 2012; Zacharias and Roff, 2000). For example, Ramos et al. (2012) established physically homogeneous coastal zones in the Northeast Atlantic region based on abiotic variables for the potential distribution of macroalgae. Their results demonstrated that met-ocean variables are strongly related to macroalgae distribution; thus, these types of variables can be used as surrogates of biological information (Ramos et al., 2016b, 2016c, 2014).

The selection of species is also a key step to ensure that they are representative of the ecosystem. A possible approach is the use of ecological engineers because they are good indicators of the health of the ecosystem, such as seagrasses (Roca et al., 2016). Seagrasses are considered a priority habitat for conservation by the EU Habitats Directive (Council of the European Commission, 1992) because they are important nursery grounds for a large number of fish and invertebrate species, thereby contributing to the maintenance of marine biodiversity and providing ecosystem services (Duarte et al., 2013; Green and Short, 2003; Ondiviela et al., 2014).

It is necessary to test whether the abiotic variables considered can be used as surrogates of selected species distribution; thus, to verify the suitability of the classification, biological data are needed (Galván et al., 2010; Ramos et al., 2016a, 2016c, 2014). One of the main problems encountered in large marine areas is the lack of an accurate homogeneous cartography. Although the increase in environmental policies has led to greater efforts in the cartography of marine communities, most submerged habitat types have not yet been comprehensively mapped in the entire Mediterranean Sea (Fraschetti et al., 2008). According to species distribution, the most endangered species are the best mapped in the Mediterranean Sea, such as *Posidonia oceanica* or *Cymodocea nodosa* (Marbà et al., 2013). Nevertheless, these cartographies are mainly regional and placed next to the coast and in the supralittoral and intertidal zones due to the high economic and time costs of sampling in the sublittoral zone (Francour, 1997; Sims et al., 2003; Azzellino et al., 2008; Panigada et al., 2008; Holcer et al., 2013; Belando et al., 2015).

The data must be obtained from the best sources available in the

study area to achieve a reliable classification. The available data sources are usually grouped into three categories: direct observations, indirect observations using remote sensing devices, and numerical modeling outputs (considered in this work as hindcast and reanalysis). For direct observations, one of the most traditional ways to collect abiotic data is through in situ measurements, where the quality is strongly dependent on the quality of the analysis results. Despite numerous surveys and observation programs carried out in the Mediterranean, a homogeneous data bank has not been compiled in a systematic way, mainly because the average density of the observations is rather low during autumn and winter and more data are available for the West Basin than for the East Basin (Brasseur et al., 1996). The growing availability and reliability of environmental information through remote sensing techniques in recent years may provide a tool to overcome the limitations of in situ measurements. Satellite imagery has the advantage of increasing data collection frequency and expanding areal coverage, offering repeatable, standardized and verifiable information over various time periods when field sampling is not available (de Barbosa Araujo et al., 2015; Muller-Karger et al., 2005; Turner et al., 2003). As a complement to these sources, numerical modeling outputs provide spatially homogenous data at high spatial and temporal resolution. These datasets historically reconstruct climate conditions providing long-time series; however, they should be validated/calibrated against real observations (Reguero et al., 2012).

The final classification needs to be objective from a statistical point of view. The use of statistical tools reduces the level of subjectivity of the final classification to meet this requirement (Huang et al., 2015; Kleisner et al., 2015; Ramos et al., 2012). Such statistical analyses have been carried out in recent decades using clustering techniques to deal with the large amount of information that is grouped using statistical methods. The self-organizing maps (SOM) and the k-means algorithm are two widely used non-linear clustering techniques. Camus et al. (2011) proposed an approach based on a combination of these techniques, and Ramos et al. (2016b,c) and Galván et al. (2016) applied this approach on the north and northwest coasts of the Iberian Peninsula and in a Cantabrian estuary, respectively. Using the heuristic formula, quantization and topographic errors for the selection of the number of units of the SOM map, objective decision rules can be applied. In addition, the SOM map has shown the capacity to deal with complex environmental data and is efficient and performs well in ecological clustering compared with conventional statistical methods (Gevrey et al., 2003; Ramos et al., 2016c; Worner et al., 2015). Similar methodologies have been successfully applied to typify the diatom communities in a Dutch delta and to characterize the fish populations in lotic systems in Serbia (Goldenberg Vilar et al., 2014; Stojković et al., 2014).

Bearing in mind the importance of the Mediterranean Sea for biodiversity conservation, the development of a statistically objective classification should be a cost-effective method to enhance the policies of environmental management (Last et al., 2010). Thus, the aim of this work is to establish an objective Mediterranean Sea classification based on biologically meaningful abiotic variables acquired in a homogeneous way. Additionally, this study provides the first approach to testing the biological relevance of the selected variables and their parameters in the Mediterranean Sea.

2. Materials and methods

2.1. Study area

The study was conducted in the entire Mediterranean Sea,

whose basin is the largest (2969 km²) and deepest (average 1460 m, maximum 5267 m) of the enclosed seas on Earth (Coll et al., 2010). The Mediterranean is a regional sea located at the crossroads of Africa, Europe, and Asia. It connects through the Strait of Gibraltar to the Atlantic Ocean in the west, through the Dardanelles Sea to the Sea of Marmara and the Black Sea in the northeast, and in the southeast, the Suez Canal links it to the Red Sea and the Indian Ocean. The Strait of Sicily divides the Mediterranean Sea into two main subregions: the West Basin (0.85 million km²) and the East Basin (1.65 million km²).

To characterize the whole study area, a mesh was defined in the projected coordinate system ETRS 1989 Zone 30N with a longitude and latitude separation of 0.5°. Coastal zones were detailed with more definition (0.125° longitude and latitude) to capture the variability over the continental shelves. The final domain has 1337 grid points.

2.2. Abiotic data

The selection of variables needed is a key step that depends on the objective and the scale of the work (Juanes et al., 2016). To define the set of abiotic variables able to explain the biological variability of the area, the following criteria were applied: (1) variables should be related to geographical seagrass distribution, (2) data must be homogeneous in the entire study area and (3) parameters have to be representative of the Mediterranean Sea conditions. After the development of a sensitivity analysis through several tests and taking into account the above-mentioned criteria, the following variables were finally selected:

- **Sea surface temperature (SST).** Temperature affects biochemical processes of organisms and determines different physiological responses, including growth rates and sexual reproduction efforts in seagrasses (Valle et al., 2014).
- **Salinity.** Due to the Mediterranean Sea characteristics, an evaporation basin, salinity is a limitation for species because they have to adapt their survival strategies. Changes in surface salinity affect the surface layer, where all primary production takes place (Vuorinen et al., 2015). In the case of seagrasses, salinity is a major environmental component that can influence the structure and function of their communities in some habitats (Nejrup and Pedersen, 2008; Sánchez-Lizaso et al., 2008; Touchette, 2007).
- **Photosynthetically active radiation (PAR).** The range of solar radiation that photosynthetic organisms are able to use is decisive in their physiology and biomass production (Best et al., 2001; Riis et al., 2012). However, above certain levels, depending on the species, radiation can have negative effects on seagrasses (photoinhibition) (Larkum et al., 2006).
- **Significant wave height (Hs).** Sea surface dynamics strongly influence the spatial distribution of seagrasses in exposed or submerged areas (Jensen and Denny, 2015; Ondiviela et al., 2014; Valle et al., 2013).
- **Depth.** Bathymetry provides information on the potential settlement areas of species in relation to the limit of light penetration into the water.

Three main data sources were employed. The salinity concentration was obtained from in situ measurements provided by the World Ocean Database (WOD) of the National Oceanic and Atmospheric Administration (NOAA)-NESDIS National Oceanographic Data Centre (NODC) (Levitus et al., 2013). To obtain comparable measures, the first 40 m mean value was employed, since it is the estimated maximum depth for photosynthetic organisms in the Mediterranean Sea (Templado González, 1995).

Photosynthetically active radiation was provided by satellite remote sensing, derived from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and the Moderate Resolution Imaging Spectroradiometer Aqua (MODIS Aqua) provided by the National Aeronautics and Space Administration (NASA) at level 3 (OB.DAAC, 2013). The SST values were supplied by the Operational Sea surface Temperature and sea-Ice concentration Analysis (OSTIA system) (Roberts-Jones et al., 2012). This dataset was designed to provide the best available estimate of the SST from a data assimilation procedure that includes a set of observations (satellites from infrared, microwave and AVHRR Pathfinder and in situ data) and operational reanalysis.

The sea surface wave dataset was from the Global Ocean Wave product GOW, developed by IHCantabria (Perez et al., 2017). The data were generated with a wave generation and propagation model, and the results were validated with satellite measurements and in situ buoy records. Bathymetry was obtained from the National Geophysical Data Center (National Oceanic and Atmospheric Administration, NOAA) (Amante and Eakins, 2009).

According to the different spatial resolutions of each dataset (Table 2), variables were obtained from the nearest available location to each grid-point of the defined geographical domain.

Parameters of the selected variables describing the average and the extreme behavior of the Mediterranean Sea were obtained, and their mutual influence was analyzed through Pearson's correlation coefficient ($r < 0.8$) (Table 2).

2.3. Classification

The selected datasets were classified following the methodology successfully applied by Ramos et al. (2016a,b,c) and Galván et al. (2016): a combination of the clustering techniques self-organizing maps (SOM) and k-means algorithm. Despite previous works being restricted to coastal areas, in this study, open seawaters were also included to ensure the accurate characterization of the whole Mediterranean Sea. This approach allowed us to account for biogeographic complexity in a large marine area.

The SOM extracts the patterns of high-dimensional data and projects them into a bidimensional organized space, allowing an intuitive visualization of the classification and the transformation of the distributions from the high-dimensional space into probability density functions on the lattice (Kohonen, 1998). The optimal map size (number of units) was chosen based on the heuristic formula proposed by Vesanto et al. (2000), $M = 5\sqrt{N}$, where M is the number of map units and N is the number of points in the mesh. In addition, quantization and topographic errors were calculated to support the number of units chosen. Quantization error is a measure of the map resolution because it is the average distance

between each data vector and its best matching unit (Kohonen, 2001). Meanwhile, topographic error measures map quality because it represents the proportion of all data vectors for which the first and second best matching units are not adjacent (Kiviluoto, 1996). Datasets of the eight abiotic parameters characterizing each grid-point were used to run the SOM and were subsequently projected onto a two-dimensional (2D) map. The SOM analysis was conducted using MATLAB 8.1 and the SOM coding solution based on SOM Toolbox for MATLAB 5 (Vesanto et al., 2000). The number of units obtained with the application of the SOM may be high for a manageable classification. Thus, as the second step of the abiotic classification, the trained map was statistically organized in clusters using the k-means algorithm (Hartigan and Wong, 1979) to identify similar clusters representing the typologies. K-means is a nonhierarchical technique that produces clusters defined by a prototype and includes the samples with a closer distribution to its prototype. Once the number of clusters is established, the prototypes (centroids) are initialized, and on each iteration, the value nearest to each centroid is identified and the centroid is then redefined as the mean of the corresponding data. The algorithm is iteratively moved until the intragroup distance is minimal and the process converges. In this work, the minimum Davies-Bouldin Index was applied between 2 and 10 clusters to determine the best number of groups (Davies and Bouldin, 1979).

2.4. Biological suitability

Four native seagrasses (*Posidonia oceanica*, *Zostera marina*, *Zostera noltei*, *Cymodocea nodosa*) were selected due to their importance in the Mediterranean Sea ecosystem. The invasive species *Halophila stipulacea* was also considered to test the fit of non-native species with the methodology proposed.

Biological data were compiled from the following global databases: Global Biodiversity Information Facility (GBIF) (GBIF, 2013), Ocean Biogeographic Information (OBIS) (OBIS, 2015) and Towards COast to COast NETWORKS project (COCONET, 2016). Filters were applied to obtain the best biological database. First, only biological records collected in the same period as the abiotic variables (1985–2013) were considered to get comparable data. Additionally, over these data, four experts in seagrasses ecology of the University of Cantabria were consulted to detect possible mistakes in the species identification or the coordinate system. To confirm or discard the possible mistakes, literature information was searched to guarantee the accuracy of the presences (Borum et al., 2004; Di Martino et al., 2006; Green and Short, 2003). Finally, to avoid overfitting, the data were reduced to only one record per mesh point. Finally, species information was transformed to the presence/absence of the spatial domain, after which the results were

Table 2
Data acquisition characteristics for the quantification of each environmental variable.

Variables	Parameters	Source	Spatial resolution	Temporal resolution	Period
Salinity	Monthly average	In situ measurements (WOD, NOAA)			2005–2013
SST	Monthly average	OSTIA dataset (NASA)	0.05°	Daily	1985–2013
	Annual average of the warmest month				
	Annual standard deviation				
PAR	Monthly average	Satellite sensor (SeaWiFS and Modis Aqua, NASA)	2 Km	Monthly	1999–2004
	Annual average of the month with the highest values				
Hs	Monthly average	Regional hindcast (GOW, IH Cantabria)	0.125°	Hourly	1985–2013
Bathymetry (ETOPO1)		National Geophysical Data Center, NOAA	0.017°		

SST, sea surface temperature; PAR, photosynthetically active radiation; Hs, significant wave height; WOD, World Ocean Database; NOAA, National Oceanic and Atmospheric Administration, NASA, National Aeronautics and Space Administration, OSTIA, Operational Sea surface Temperature and sea-Ice concentration Analysis, GOW, Global Ocean Wave.

projected to SOM and k-means clusters to visualize the species spatial distribution according to abiotic classification.

3. Results

3.1. Abiotic data

The general trend of salinity was to increase eastward, although there were some exceptions. In the Aegean Sea, salinity increased from the north to the south, whereas on the north and west coasts of the Adriatic Sea, salinity was lower than in other nearshore areas. In addition, in the Gulf of Lion, some points with high salinity were observed (Fig. 1).

Regarding the monthly average SST, a clear north-south and west-east gradient was observed, with the coldest temperatures in the Alborán Sea and in the north of Algero-Provençal Basin, Tyrrhenian Sea, Adriatic Sea and Aegean Sea. In contrast, the highest values were situated in the east of the Levantine Basin. The pattern in the annual standard deviation was not so clear. The highest values were observed in semi-enclosed coastal regions, such as the Aegean Sea and the Sea of Marmara, the north of the Adriatic Sea and the Gulf of Gabès. The lowest values were found in the Alborán Sea and the west of Turkey. The annual average of the warmest

month, August, presented a similar spatial pattern to the average SST map, with isolated coldest patches (the Alborán Sea, the north of the Algero-Provençal Basin and the Aegean Sea) and the warmest ones in the east of the Levantine Sea, in the Gulf of Sidra and the north of Sicily (Fig. 1).

As occurred with the average SST, monthly average PAR showed a clear north-south gradient. Nevertheless, a difference between basins was found for the June annual average (the month with the highest PAR values): the West Basin exhibited lower values, and the north of the East Basin exhibited higher values (Fig. 1).

As can be expected, significant wave height and depth showed a gradient from coastal areas, where the lowest values were in the open sea. In general, the western Mediterranean Sea has higher waves, specifically over the Balearic Sea located between the eastern coast of Spain, the southern coast of France, and the islands of Corsica and Sardinia. Enclosed seas, such as the Adriatic Sea and the Aegean Sea, exhibited low values. In contrast, the deepest area of the Mediterranean Sea is in the Ionian Sea (Fig. 1).

3.2. Classification

Based on the heuristic formula of Vesanto et al. (2000), the map size selected was 182 units (13×14 groups). The trained map had a

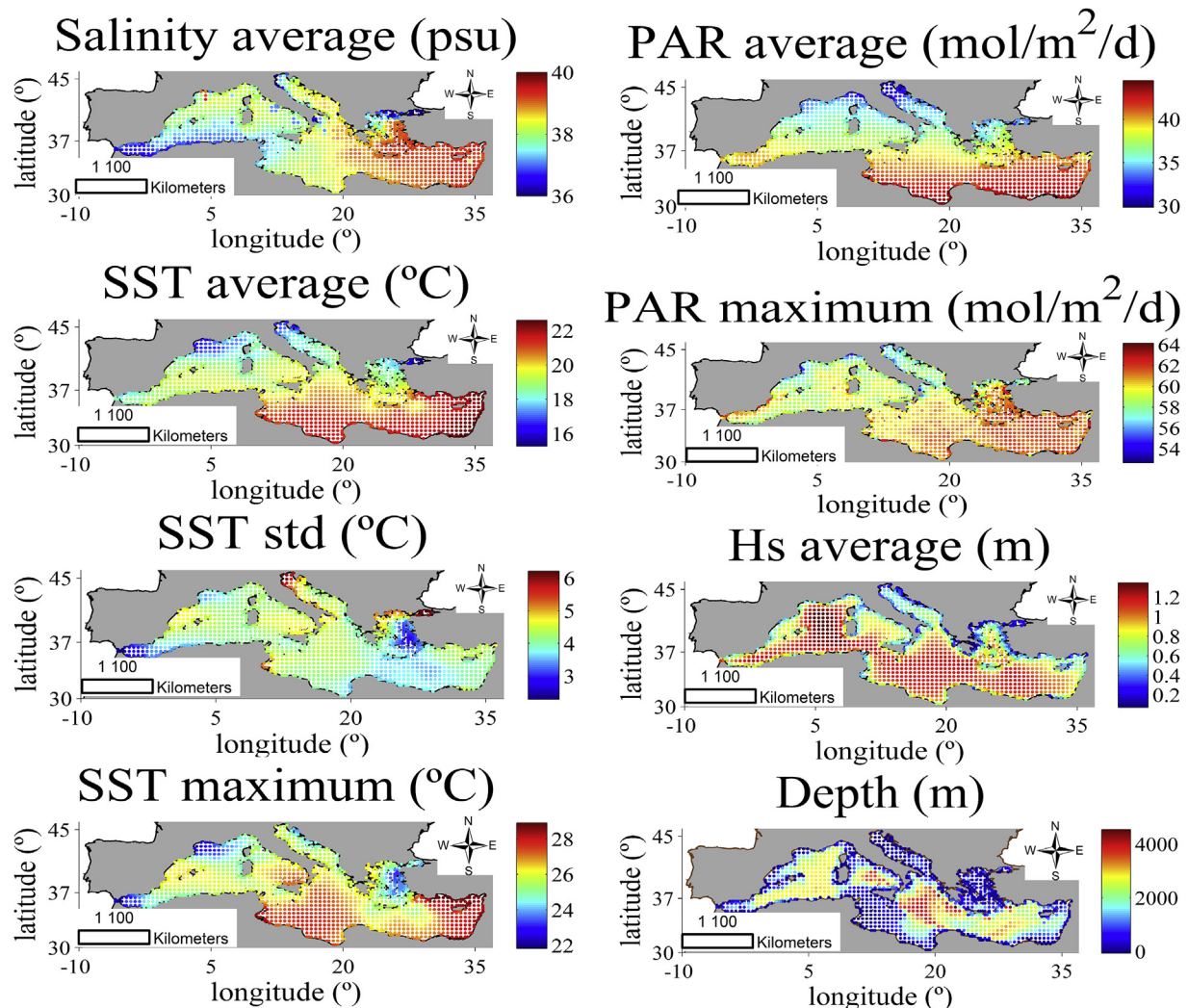


Fig. 1. Spatial distribution maps of the parameters of the abiotic variables along the Mediterranean Sea. From top left column: average salinity, average sea surface temperature (SST), standard deviation SST, maximum SST. From top right column: average photosynthetically active radiation (PAR), maximum PAR, average wave height (Hs) and depth.

quantization error of 0.143 and a topographic error of 0.027. Each unit of the SOM gathered a different number of grid points, with similar characteristics, preserving neighborhood relationships.

The SST average, SST maximum and PAR average showed similar patterns, with the highest values in the bottom right SOM units and the lowest values on the opposite side. In addition, the Hs average and depth had a positive association, with low Hs values in the shallow areas and the highest values in the deep zones (Fig. 2a).

The Davies-Bouldin Index was calculated for two to ten k-means clusters, obtaining values between 0.79 and 1.27. The optimal number of k-means clusters was seven considering the minimum Davies-Bouldin Index (0.79). The seven typologies in the SOM lattice and over the Mediterranean Sea are shown in Fig. 2. Some typologies exhibit a non-continuous geographic dispersal due to the exclusion of abiotic parameters.

The typologies obtained can be classified in two groups: one with low radiation, salinity and SST (typologies “Algerian Basin (I),” “Alborán-Aegean (II),” “North Coast (III)” and “Deep (IV)”) and the other characterized by saltier and hotter waters (typologies “East Basin deep (V),” “South East Basin (VI)” and “East Basin coast (VII)”).

Fig. 3 shows the spatial distribution and multivariate distribution of the parameters for each typology. However, some differences among them can be observed:

- **Typology I, Algerian Basin:** mainly restricted to the open sea in the West Basin, with low SST, PAR and salinity values. This typology was deeper and more exposed than typologies “Alborán-Aegean (II)” and “North Coast (III)” but less than typology “Deep (IV).”
- **Typology II, Alborán-Aegean:** characterized by the influence of the cold water entrance with shallower areas, as in the “North Coast (III)” typology. However, this typology presented more stable SST and higher Hs and radiation values.
- **Typology III, North Coast:** encompassed shallow areas with the lowest values for Hs, radiation, SST and salinity. Nevertheless, the SST standard deviation was high.
- **Typology IV, Deep:** the key characteristic of this typology was the highest depth and Hs. Salinity was low as in previous typologies, while the values of the other variables were moderate.

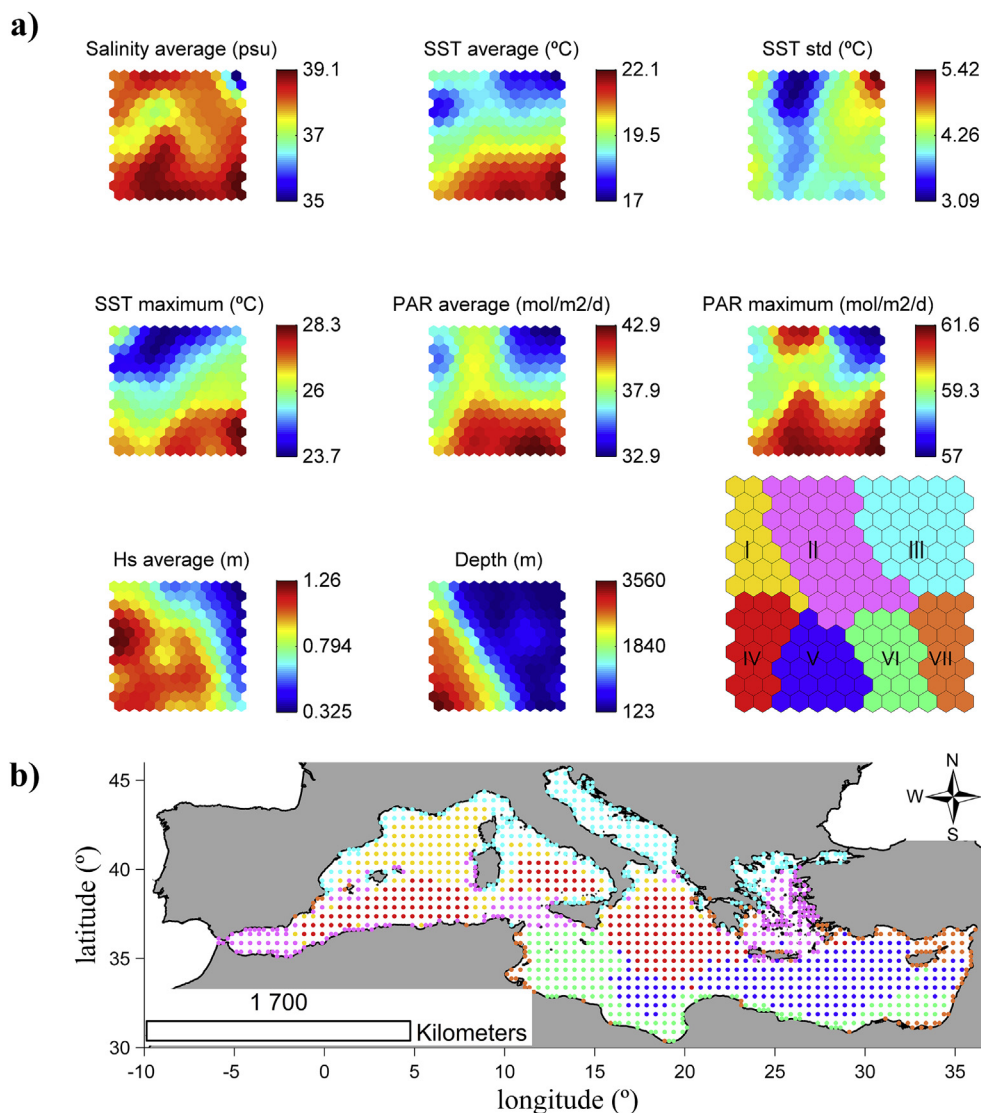


Fig. 2. (a) Gradient analysis of each abiotic parameter on the trained self-organizing map (SOM). Right down, visualization of the k-means results on the SOM plane. (b) Map of the obtained typologies in the Mediterranean Sea by the abiotic classification (based on SOM and k-means statistical analyses results). SST, sea surface temperature; PAR, photosynthetically active radiation; Hs, significant wave height; std, standard deviation.

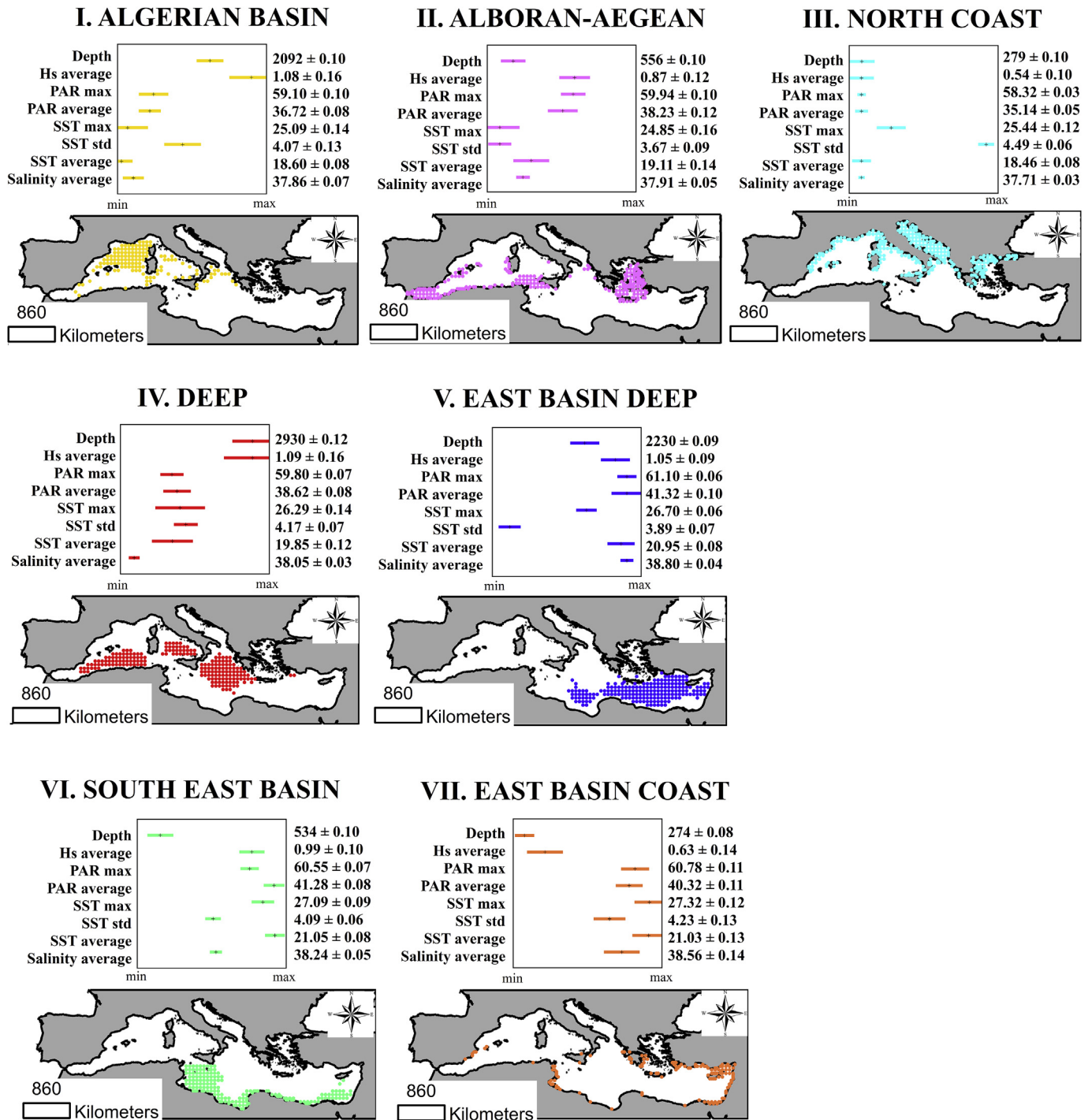


Fig. 3. The spatial distribution and box-plot graphs of the normalised values of the parameters for each typology. The mean value of each parameter is symbolized as a black cross, while the limits of the rectangle represent the standard deviation range. Hs, significant wave height; PAR, photosynthetically active radiation; SST, sea surface temperature; max, maximum; std, standard deviation.

- **Typology V, East Basin deep:** in this typology, the highest radiation and salinity with high SST stability stood out as a difference between typologies “South East Basin (VI)” and “East Basin coast (VII).” Another remarkable characteristic of this typology with regard to other similar typologies (“South East Basin (VI)” and “East Basin coast (VII)”) was its great depth.
- **Typology VI, South East Basin:** the main difference from typologies “East Basin deep (V)” and “East Basin coast (VII)” was

that it encompassed the shallowest points. The main similarity with them was the high values of radiation and temperature. This typology was characterized by being exposed.

- **Typology VII, East Basin coast:** this typology was the shallowest and the most sheltered within the East Basin. Salinity and temperature were also higher than in the typologies “East Basin deep (V)” and “South East Basin (VI)”.

3.3. Biological suitability

Data on the presence of seagrasses in the Mediterranean Sea compiled from the sources described in the section “2.4 Biological suitability” are shown in Fig. 4 for each species separately.

The total and relative frequency values for each species over the SOM units and the k-means clusters are shown in Fig. 5, illustrating

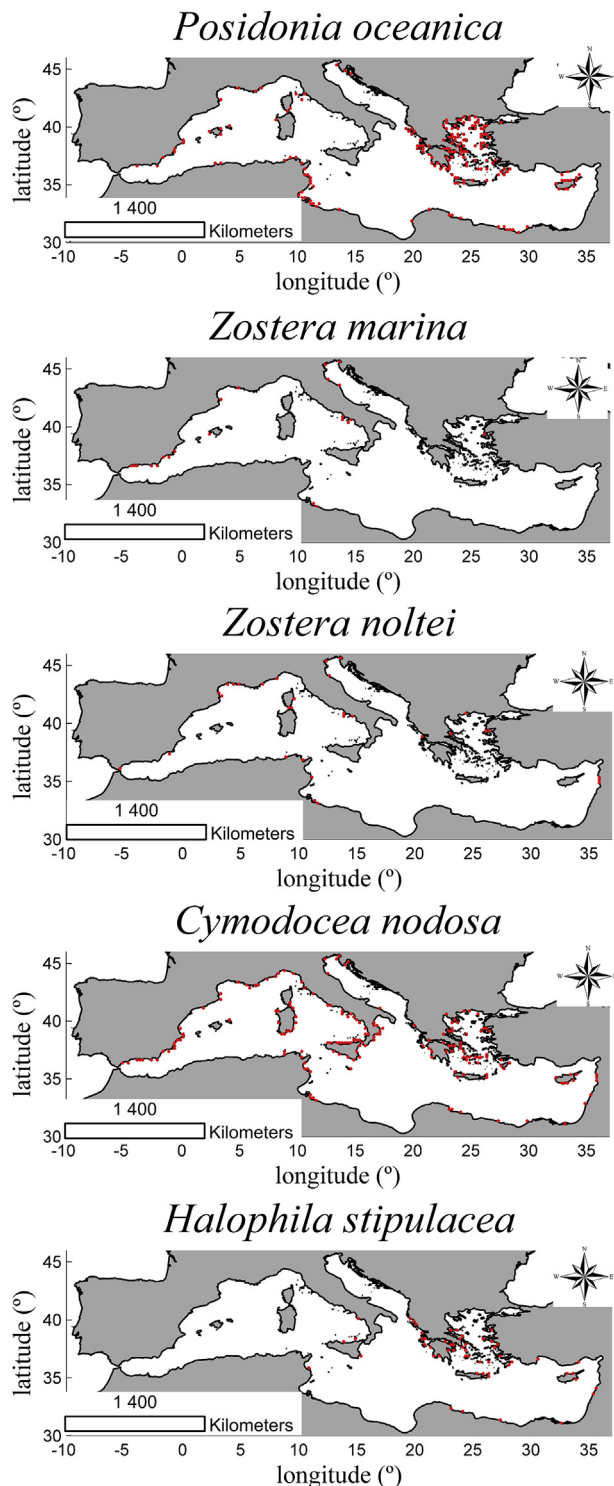


Fig. 4. The spatial distribution of the seagrasses considered along the Mediterranean Sea.

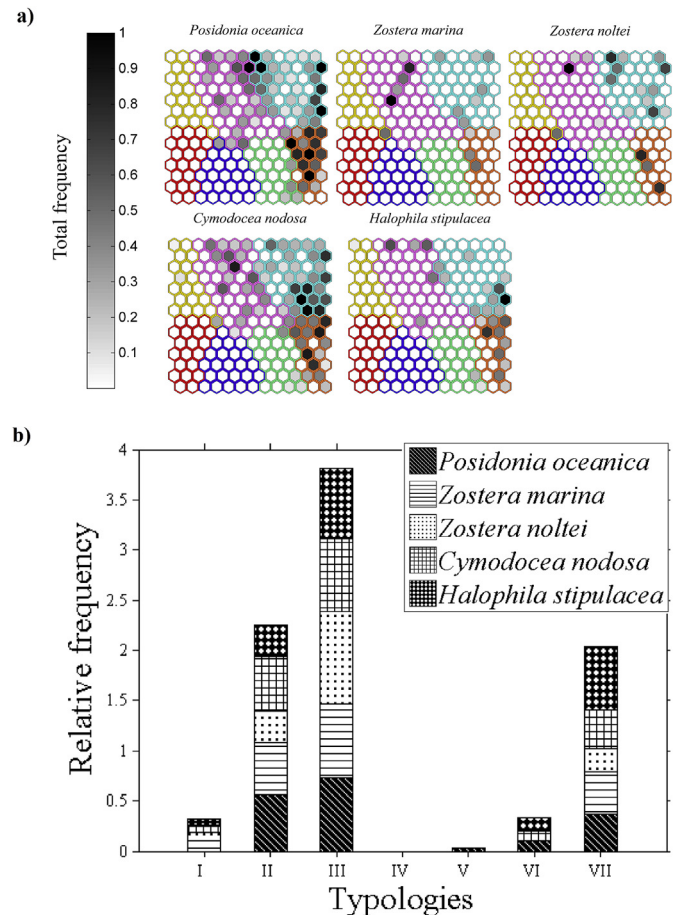


Fig. 5. (a) Visualization of the total frequency of mesh points cover of seagrasses considered (light = low frequency, dark = high frequency). (b) Bar graph for normalized relative frequency values of each species for each typology.

their preferences.

In general, the classification was in agreement with the ecological requirements of the considered seagrasses. The coastal typologies (“North Coast (III)”, “Alborán-Aegean (II)” and “East Basin coast (VII)”) had the highest frequencies according to the seagrass preference in shallow areas. The results showed the highest frequency of typology “North Coast (III)”, which had shallow points with colder waters and less radiation and salinity than the “East Basin coast (VII)” typology. It was also characterized by a shorter wave height than the “East Basin coast (VII)”. The high frequency of the invasive seagrass *H. stipulacea* compared to the other species was remarkable for the “East Basin coast (VII)” typology. This typology was mainly confined to the East Basin with the highest values of the maximum SST and radiation. However, the frequency of the invasive species was lower than that of the other seagrasses, with the exception of *Z. noltei*, in the typology “Alborán-Aegean (II)”, characterized by cold waters and intermediate values of wave height, radiation and salinity. Regarding native species, *P. oceanica*, *Z. marina* and *C. nodosa* exhibited a higher preference for typologies II and VII than *Z. noltei*, while in the typology “North Coast (III)”, the trend was the opposite. The main difference between these typologies is that “North Coast (III)” presented higher SST standard deviation and lower salinity, radiation and significant wave height values. The typologies where seagrasses showed low frequency (“Algerian Basin (I)”, “Deep (IV)”, “East Basin deep (V)” and “South East Basin (VI)”) were characterized by highly significant wave height or depth values. Thus, regarding the seagrass

frequency over the abiotic classification, the species distributions were in agreement with the defined typologies.

4. Discussion

The results presented in this work confirm the ability of the proposed methodology to classify the main regions in the Mediterranean Sea, taking into account its ecological relevance for seagrasses. This approach allows to the detection of areas linked by biological requirements, even if they are geographically separated.

4.1. Abiotic data

The quantification of variables and their parameters in a standardized fashion with the required resolution is a key step achieved with the use of remote sensing and numerical modeling datasets. These datasets provide continuous and uniform information throughout the study area (Devred et al., 2007; Gregr and Bodtger, 2006; Ramos et al., 2016c, 2012; Turner et al., 2003). Therefore, the suitability of the procedure used in this work to characterize the coastal and open waters of a broad area is demonstrated, showing similar patterns to the results obtained in other studies.

The general pattern of increasing the annual average salinity eastward with a mean value in the West Basin of 36.2‰ and of 39‰ in the East Basin, described by other studies (Coll et al., 2010; European Environment Agency (EEA), 2002; Lacoue-Labarthe et al., 2016), is also reflected in this work. In addition, the documented exceptions to this pattern, such as the freshwater influence of the Black Sea in the Aegean Sea and the entrance of less salty waters through the Strait of Gibraltar from the Atlantic Ocean, are captured in the present study (Coll et al., 2010; Georgiou et al., 2015; Poulos and Collins, 1997; Rodríguez, 1982). Furthermore, the results provide evidence of the ability of selected sources to detect local processes, as for the Po River flume on the north and west coast of the Adriatic Sea, where salinity is lower than in neighboring areas (Falcieri et al., 2013). In addition, the presence of saltier and colder waters in the Gulf of Lion is in agreement with the findings of other authors (Millot, 1999; Sarda et al., 2004). These conditions are due to the influence of the Mistral, a strong, dry and cold northwesterly wind that blows from southern France, favoring evaporation and the loss of heat.

Concerning the average SST values, the previously described pattern of cold water entering from the Atlantic and warming up towards the east is also in agreement with our results (Brasseur et al., 1996; Coll et al., 2010; Lacoue-Labarthe et al., 2016; Rodríguez, 1982). The approach described in this study is also able to detect the upwelling zones (the Aegean Sea and the north of the Adriatic Sea), where variability is high, as can be expected due to the characteristics of this phenomenon, which implies that colder water from the bottom moves towards the ocean surface (Marbà et al., 2015; Rodríguez, 1982). This work also detects the influence of the thermocline, which is less structured during summer than in winter. As a result, the exchanges that occur during the warmest months may result in severe local variations, as seen in the presence of patches in the maximum SST distribution (Marbà et al., 2015).

The incident radiation trend is in agreement with the latitudinal gradient north to south. Nevertheless, for the maximum PAR, the gradient is mainly longitudinal, with lower values in the West Basin and higher radiation in the East Basin. Although it has not been possible to find previous studies of PAR distribution in the Mediterranean Sea, these results can be explained by the work of Bat-Oyun et al. (2012), who established the influence of different factors on photosynthetically active radiation. Within these factors, a notable possibility is that the African dust during dry months in the

area modifies the general pattern (Bergametti et al., 1992).

The overall patterns in wave energy are in agreement with the water depth, as they are strongly related to coastal points and enclosed seas (Adriatic Sea or Aegean Sea). As described by Cavaleri et al. (2004), the shelf causes less energetic waves, whereas in deeper areas, such as the Algerian and the Ionian basins, the bottom does not limit wave height.

Despite the close agreement of the characterization of the Mediterranean Sea with previous works, some questions require further development. It would be more precise to consider other key variables for species distribution, such as the substrate characteristics (Roff and Taylor, 2000; Templado González, 1995) or the use of bottom shear stress as a measure of the energy of the system (Tomás et al., 2012). Likewise, the parameters considered must be studied in detail to select those that best explain the biological behaviors of species. In this work, the average, maximum and minimum values are used, but it would be interesting to consider the use of parameters that are critical for certain species, such as the number of days in a year that some values are exceeded or the interannual variability of events (Jensen and Denny, 2015; Sánchez Lisazo, 1993; Unsworth et al., 2015). This approach will allow improvements in the power of using abiotic variables as surrogates for species distribution (Seabra et al., 2015), taking into account the met-ocean variables (Puente et al., 2017).

4.2. Classification

The results presented in this work provide evidence for the suitability of the methodological approach to obtain subdivisions for the entire Mediterranean Sea based on accurate and homogeneous abiotic data through the application of a combination of clustering techniques (SOM and k-means). This framework has been successfully applied by Ramos et al. (2016c) and Galván et al. (2016) for regions with different met-ocean conditions.

This combination of clustering techniques represents a considerable improvement compared with the classifications that consider only the k-means algorithm (Gabrie et al., 2012) but at the same time, the methodology is less complex than those presented by other authors (Nieblas et al., 2014; Reygondeau et al., 2017) while also providing good results and easier application.

The typologies obtained were able to depict the general patterns described in the Mediterranean Sea and to detect the main differences between areas. The water-mass exchange barrier existing in the Strait of Sicily (Bonanno et al., 2014; Giaccone and Sortino, 1974; Micheli et al., 2005; Rodríguez, 1982) is clearly distinguished in this work, which supports the ability of the proposed methodology to detect oceanographic differences among the obtained typologies. Therefore, typologies “Algerian Basin (I)”, “Alborán-Aegean (II)”, “North Coast (III)” and “Deep (IV)” can be recognized as representative of the West Basin because they present colder and less salty waters. In contrast, typologies “East Basin deep (V)”, “South East Basin (VI)” and “East Basin coast (VII)” depict the East Basin characteristics, with hotter and saltier waters and higher radiation. In addition to this distinction, the classification obtained has been proven to detect one of the most determinant factors in seagrass survival, depth as a surrogate of light availability. Through this differentiation, coastal areas mainly include the typologies “North Coast (III)”, “East Basin coast (VII)”, “Alborán-Aegean (II)” and “South East Basin (VI)”; meanwhile, the deepest areas are included in the typologies “Deep (IV)” and “East Basin deep (V).” In each of the aforementioned groups (West and East Basins), one of the typologies is characterized by encompassing sheltered points, the typology “North Coast (III)” in the West Basin and the typology “East Basin coast (VII)” in the East Basin. Existing studies have shown that wave energy is a determining factor in the spatial

distribution of seagrass meadows (Infantes et al., 2011); thus, the differentiation of these areas from the exposed areas supports the robustness of the methodology used in this study. In addition, the typology “North Coast (III)” is linked to upwelling areas, as the high SST variation reflects. The salinity of this typology is the lowest, related to rivers with high flows in the northwest of the Adriatic Sea and the Gulf of Lion (Po: 1540 m³/s and Rhone: 1710 m³/s, respectively). In the Aegean Sea, the influence of the Black Sea water is observed in the salinity values (Falcieri et al., 2013).

The main typologies recognized in this study differed from the geographical limits established in previous classifications (Bianchi, 2007; Notarbartolo di Sciara and Agardy, 2010a; Spalding et al., 2007). These subdivisions were established based on geomorphological and biogeographic features, while we consider met-ocean variables. As a result, the proposed classification, despite not having as clear of boundaries as previous classifications, reflects possible links between areas geographically separated but ecologically related, such as the Alborán Sea and the Aegean Sea or the southern Algerian Basin and the Ionian Sea. Some of these differences are motivated by the inclusion of key variables for species not considered in similar studies (Gabrie et al., 2012; Nieblas et al., 2014; Reygondeau et al., 2017) such as significant wave height or photosynthetically active radiation, which clearly influence species distributions. In addition, the use of extreme and variable parameters considered in this work is remarkable due to their importance in the definition of species thresholds (Makino et al., 2015). This feature allows the characterization of the Mediterranean processes in a more reliable way by taking into consideration the relationships between geographically separated areas.

4.3. Biological suitability

In general, the analysis of taxa and their frequency over typologies confirm the biological relevance of the methodology with respect to seagrass distribution. The ability of the methodology to explain the seagrasses distribution and to distinguish between species requirements allows its use as a powerful tool to manage large regions.

P. oceanica is mainly present in the typologies “North Coast (III)” and “Alborán-Aegean (II)”. It is also present in the typology “East Basin coast (VII)” but with a marked decrease in frequency. This finding is consistent with its ecology because they are coastal typologies (Luque and Templado González, 2004; Marín-Guirao et al., 2011; Short et al., 2007; Templado González, 1995) with a temperature range that is in agreement with *P. oceanica* requirements (Bay, 1984; Larkum et al., 2006). Concerning salinity, the typologies “Alborán-Aegean (II)” and “North Coast (III)” present an average value of 37.81‰, which is in agreement with the optimum of 38‰ described by Sánchez-Lizaso et al. (2008). Despite being a stenohaline species, *P. oceanica* is present in the typology “East Basin coast (VII)”, where values are higher (average salinity of 38.56‰) but are under the threshold of damage and in the range established by other authors (Larkum et al., 2006; Telesca et al., 2015).

The frequency of occurrence of *Z. marina* in the typologies “North Coast (III)”, “Alborán-Aegean (II)” and “East Basin coast (VII)” is very similar to that of *P. oceanica*, with a clear preference for coastal typologies, as it is located from the intertidal zone to a few meters deep (Green and Short, 2003), within the range of temperatures common in these typologies (Lee et al., 2007; Nejrup and Pedersen, 2008). The obtained classification is able to distinguish the preference of *Z. marina* for settlement locations that can exist in areas with a wider range of hydrodynamism than *P. oceanica*, forming vast meadows in sheltered areas and isolated patches in exposed ones (Ondiviela et al., 2005; Short et al., 2010a). In the

Mediterranean Sea, *Z. marina* is considered a relict species, seemingly rare in the eastern part (Borum et al., 2004; Green and Short, 2003), which explains its presence in typologies with a salinity higher than its tolerance range of 5‰–35‰ (Short et al., 2010a).

In the Mediterranean, *Z. marina* co-occurs with *Z. noltei*, which is reflected in the classification obtained because both species are present in the same typologies but with some differences in frequency. *Z. noltei* shows a clear preference for the typology “North Coast (III)” because this species can occur from mesohaline to euhaline environments (Fernández-Torquemada and Sánchez-Lizaso, 2011; Luque and Templado González, 2004; Short et al., 2010b) and is adapted to colder waters than *P. oceanica* (Peralta, 2000).

The classification shows the overlap in *C. nodosa*, *H. stipulacea* and *P. oceanica* niches because they are present in the same typologies with some specificities. Meanwhile, *C. nodosa* usually forms mixed meadows with *P. oceanica* because their ecological requirements are very similar (Pérez and Romero, 1994). The origin of *H. stipulacea*, a lessepsian species, determines that it most commonly occurs in areas with characteristics similar to those of the Red Sea. *C. nodosa* is considered a pioneer species; thus, its ranges of tolerance are wider than in other species, as illustrated by the typologies where it is present (Borum et al., 2004; Chefaoui et al., 2016; Fernández-Torquemada and Sánchez-Lizaso, 2011; Olsen et al., 2012).

The alien seagrass *H. stipulacea* has the highest relative frequency in the typology “East Basin coast (VII)”, with a primary presence in the East Basin because it entered the Mediterranean Sea through the Suez Canal. Therefore, the typological characteristics are in agreement with the ecology of *H. stipulacea*, whose optimal temperature is very similar to the mean value of the typology “East Basin coast (VII)” (21.5 °C vs 21.03 °C) (Gambi et al., 2009; Short et al., 2010c), and the species copes well with the high salinity of this typology (Lipkin, 1975). Despite this agreement with the typology “East Basin coast (VII)”, due to its migrant nature, *H. stipulacea* tolerates a wide range of environmental conditions (Otero et al., 2013), which explains its presence in other typologies, especially in “North Coast (III)”.

Although in this work seagrasses have been considered, the proposed methodology could be applied also to other flora or animal species by adjusting the input variables and parameters. For example, taking into account the spatial distribution of the shark *Cetorhinus maximus*, according to the databases of the Materials and methods section, it can be observed its preference for the “North Coast (III)” typology, which is in agreement with the behaviour of this fish, which moves to shallow depths between 0 and 20 m during part of the day to feed on zooplankton *Calanus helgolandicus* (Sims et al., 2005). Additionally, basking shark prefers cold waters with high variability (Cotton et al., 2005), which characterizes this typology.

Our results show a general agreement of the typologies obtained with the considered seagrass ecology, which constitutes a very interesting finding for marine areas management. However, only presence data have been considered, meanwhile it will be necessary to have quantitative information and absence data to reach a complete validation. Besides the survey effort in the Mediterranean Sea to map the species presence is not the same in the two basins, and the understanding of their responses to environmental variables and their tolerance thresholds is far from complete (Marbà et al., 2015). Therefore, there remains insufficient knowledge on species encompassing their entire distributional range and their ecology and a complete biological validation of the classification is required.

5. Conclusions

In conclusion, the methodology applied in this work is able to classify the whole Mediterranean Sea in an unbiased manner into biologically relevant typologies, enabling the identification of areas geographically separated but important for species distribution. This approach supports the link between met-ocean variables and species distribution and the importance of including them in ecological modeling. Additionally, this study shows the suitability of the selected clustering methods for grouping abiotic data from reliable sources, which provides an objective procedure for the classification of large areas and its use as surrogates of species distributions.

According to our results, seven areas can be recognized in the Mediterranean Sea. The obtained typologies are able to recognize the oceanographic barrier in the Strait of Sicily and to cluster the results into two groups: one for typologies “South East Basin (VI)”, “East Basin deep (V)” and “East Basin coast (VII)” and the other for typologies “Algerian Basin (I)” and “North Coast (III)”, with differences clearly marked by temperature, salinity and radiation. Within this grouping, it is possible to distinguish coastal (typologies “Alborán-Aegean (II)”, “North Coast (III)”, “South East Basin (VI)” and “East Basin coast (VII)”) and deep areas (typologies “Algerian Basin (I)”, “Deep (IV)” and “East Basin deep (V)”). The influence of river discharges and the entrance of water from other seas are also reflected in typologies “North Coast (III)” and “Algerian Basin (I)”, respectively.

From a biological point of view, the typologies obtained are consistent with the distribution and ecological requirements of the considered seagrasses. Therefore, the link between surrogates and targets can be considered strong. As can be expected, seagrasses show a clear preference for coastal sites, with different frequencies according to their ecology.

The applications of this approach are broad because obtaining spatially and temporal homogeneous abiotic data is easier than a biological approach. Therefore, this approach provides a powerful tool for managers to attain ecosystem-based conservation of coastal and marine waters. Once the present classification and its relationship with species are known, it will be possible to develop hypotheses about changes in the distribution of Mediterranean Sea species due to global warming (Lacoue-Labarthe et al., 2016), which could support the sustainable management of marine biodiversity.

Although requiring further development, the results presented here show the ecological value of the classification obtained with the target species and, consequently, the ability of the methodology proposed to define typologies with biological implications in large areas using abiotic variables as surrogates of biological data. This approach constitutes a powerful tool for managing these zones.

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References

- Amante, C., Eakins, B.W., 2009. ETOPO1 1 Arc-minute Global Relief Model: Procedures, Data Sources and Analysis [WWW Document]. NOAA Tech. Memo. NESDIS NGDC-24. Natl. Geophys. Data Center, NOAA. <http://dx.doi.org/10.7289/V5C8276M>.
- Azzellino, A., Gaspari, S., Airoldi, S., Nani, B., 2008. Habitat use and preferences of cetaceans along the continental slope and the adjacent pelagic waters in the western Ligurian Sea. *Deep. Res. Part I Oceanogr. Res. Pap.* 55, 296–323. <http://dx.doi.org/10.1016/j.dsr.2007.11.006>.
- Bat-Oyun, T., Shinoda, M., Tsubo, M., 2012. Effects of cloud, atmospheric water vapor, and dust on photosynthetically active radiation and total solar radiation in a Mongolian grassland. *J. Arid. Land* 4, 349–356. <http://dx.doi.org/10.3724/SPJ.1227.2012.00349>.
- Bay, D., 1984. A field study of the growth dynamics and productivity of *Posidonia oceanica* (L.) delile in Calvi Bay, Corsica. *Aquat. Bot.* 20, 43–64. [http://dx.doi.org/10.1016/0304-3770\(84\)90026-3](http://dx.doi.org/10.1016/0304-3770(84)90026-3).
- Belando, M.D., García Muñoz, R., Ramos Segura, A., Franco-Navarro, I., Bernardeau-esteller, J., García Moreno, P., Ruiz, J.M., 2015. Distribution and Abundance of *Cymodocea nodosa* Meadows and *Pinna nobilis* Populations in the Mar Menor Coastal Lagoon (Murcia, SE of Spain). *PeerJ PrePrints*.
- Bergametti, G., Remoudaki, E., Losno, R., Steiner, E., Chatenet, B., Buat-Menard, P., 1992. Source, transport and deposition of atmospheric phosphorus over the Northwestern Mediterranean. *J. Atmos. Chem.* 14, 501–513.
- Berline, L., Rammou, A.M., Doglioli, A., Molcard, A., Pretrenko, A., 2014. A connectivity-based eco-regionalization method of the mediterranean sea. *PLoS One* 9, 3–11. <http://dx.doi.org/10.1371/journal.pone.0111978>.
- Best, E.P., Buzzelli, C.P., Bartell, S.M., Wetzel, R.L., Boyd, W.A., Doyle, R.D., Campbell, K.R., 2001. Modeling submersed macrophyte growth in relation to underwater light climate: modeling approaches and application potential. *Hydrobiologia* 444, 43–70. <http://dx.doi.org/10.1023/A:1017564632427>.
- Bianchi, C.N., 2007. Biodiversity issues for the forthcoming tropical Mediterranean Sea. *Hydrobiologia* 580, 7–21. <http://dx.doi.org/10.1007/978-1-4020-6156-1>.
- Bonanno, A., Placenti, F., Basilone, G., Mifsud, R., Genovese, S., Patti, B., Bitetto, M. Di, Aronica, S., Barra, M., 2014. Variability of water mass properties in the Strait of Sicily in summer period of 1998 – 2013. *Ocean. Sci.* 10, 759–770. <http://dx.doi.org/10.5194/os-10-759-2014>.
- Borum, J., Duarte, C.M., Krause-Jensen, D., Greve, T.M., 2004. European Seagrasses: an Introduction to Monitoring and Management. Management. <https://doi.org/EVK3-CT-2000-00044>.
- Brasseur, P., Beckers, J.M., Brankart, J.M., Schoenauen, R., 1996. Seasonal temperature and salinity fields in the Mediterranean Sea: climatological analyses of a historical data set. *Deep. Res. Part I Oceanogr. Res. Pap.* 43, 159–192. [http://dx.doi.org/10.1016/0967-0637\(96\)00012-X](http://dx.doi.org/10.1016/0967-0637(96)00012-X).
- Camus, P., Mendez, F.J., Medina, R., Cofino, A.S., 2011. Analysis of clustering and selection algorithms for the study of multivariate wave climate. *Coast. Eng.* 58, 453–462. <http://dx.doi.org/10.1016/j.coastaleng.2011.02.003>.
- Cavaleri, L., Bertotti, L., Sclavo, M., Athanassoulis, G.A., Stefanakos, Ch.N., Gerostathis, T.P., Gaillard, P., Ravazzola, P., Kontolios, C., Ramieri, E., Dentone, L., Noel, C., Viala, C., Lefevre, J.M., 2004. Wind and Wave Atlas of the Mediterranean Sea. Western European Armaments Organisation Research Cell.
- Chefaoui, R.M., Assis, J., Duarte, C.M., Serrão, E.A., 2016. Large-scale prediction of seagrass distribution integrating landscape metrics and environmental factors: the case of *Cymodocea nodosa* (Mediterranean–Atlantic). *Estuaries Coasts* 39, 123–137. <http://dx.doi.org/10.1007/s12237-015-9966-y>.
- COCONET, 2016. Towards COast to COast NETworks of Marine Protected Areas (From the Shore to the High and Deep Sea) Coupled with Sea-based Wind Energy Potential [WWW Document]. FP7 grant Agreement. no.287844. URL. <http://coconetgis.ismar.cnr.it/>. (Accessed 30 May 2015).
- Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Lasram, F.B.R., Aguzzi, J., Ballesteros, E., Bianchi, C.N., Corbera, J., Dailianis, T., Danovaro, R., Estrada, M., Frogliia, C., Galil, B.S., Gasol, J.M., Gertwage, R., Gil, J., Guilhaumon, F., Kesner-Reyes, K., Kitsos, M.S., Koukouras, A., Lampadariou, N., Laxamana, E., de la Cuadra, C.M.L.F., Lotze, H.K., Martin, D., Mouillot, D., Oro, D., Raicevich, S., Rius-Barile, J., Saiz-Salinas, J.I., Vicente, C.S., Somot, S., Templado, J., Turon, X., Vafidis, D., Villanueva, R., Voultsiadou, E., 2010. The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PLoS One* 5. <http://dx.doi.org/10.1371/journal.pone.0011842>.
- Cotton, P.A., Sims, D.W., Fanshawe, S., Chadwick, M., 2005. The effects of climate variability on zooplankton and basking shark (*Cetorhinus maximus*) relative abundance off southwest Britain. *Fish. Oceanogr.* 14, 151–155. <http://dx.doi.org/10.1111/j.1365-2419.2005.00331.x>.
- Council of the European Commission, 1992. Council directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora. *Official Journal of the European Communities*.
- Davies, D.L., Bouldin, D.W., 1979. A Cluster Separation Measure. *IEEE Trans. Pattern Anal. Mach. Intell. PAMI-1*, pp. 224–227.
- de Barbosa Araujo, C.C., Atkinson, P.M., Dearing, J.A., 2015. Remote sensing of ecosystem services: a systematic review. *Ecol. Indic.* 52, 430–443. <http://dx.doi.org/10.1016/j.ecolind.2015.01.007>.
- Devred, E., Sathyendranath, S., Platt, T., 2007. Delineation of ecological provinces using ocean colour radiometry. *Mar. Ecol. Prog. Ser.* 346, 1–13. <http://dx.doi.org/10.3354/meps07149>.
- Di Martino, V., Blundo, M.C., Tita, G., 2006. The mediterranean introduced seagrass

- Halophila stipulacea in eastern sicily (Italy): temporal variations of the associated algal assemblage. *Life Environ.* 56, 223–230.
- Duarte, C.M., Losada, I.J., Hendriks, I.E., Mazarrasa, I., Marbà, N., 2013. The role of coastal plant communities for climate change mitigation and adaptation. *Nat. Clim. Chang.* 3, 961–968. <http://dx.doi.org/10.1038/nclimate1970>.
- European Commission, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive). Official Journal of the European Communities.
- European Environment Agency (EEA), 2002. Europe's Biodiversity — Biogeographical Regions and Seas, EEA Report No 1/2002. Copenhagen.
- Falcieri, F.M., Benetazzo, A., Sclavo, M., Russo, A., Carniel, S., 2013. Po River plume pattern variability investigated from model data. *Cont. Shelf Res.* 1–12. <http://dx.doi.org/10.1016/j.csr.2013.11.001>.
- Fernández-Torquemada, Y., Sánchez-Lizaso, J.L., 2011. Responses of two Mediterranean seagrasses to experimental changes in salinity. *Hydrobiologia* 669, 21–33. <http://dx.doi.org/10.1007/s10750-011-0644-1>.
- Francour, P., 1997. Fish assemblages of Posidonia oceanica beds at Port Cros (France, NW Mediterranean): assessment of composition and long-term fluctuations by visual census. *Mar. Ecol. Della Stn. Zool. Di Napoli I* 18, 157–173. <http://dx.doi.org/10.1111/j.1439-0485.1997.tb00434.x>.
- Fraschetti, S., Terlizzi, A., Boero, F., 2008. How many habitats are there in the sea (and where)? *J. Exp. Mar. Bio. Ecol.* 366, 109–115. <http://dx.doi.org/10.1016/j.jembe.2008.07.015>.
- Gabrie, C., Lagabriele, E., Bissery, C., Crochelet, E., Meola, B., Webster, C., Claudet, J., Chassanite, A., Marinesque, S., Robert, P., Goutx, M., 2012. The Status of Marine Protected Areas in the Mediterranean Sea.
- Galván, C., Juanes, J.A., Puente, A., 2010. Ecological classification of European transitional waters in the North-East Atlantic eco-region. *Estuar. Coast. Shelf Sci.* 87, 442–450. <http://dx.doi.org/10.1016/j.ecss.2010.01.026>.
- Galván, C., Puente, A., Castanedo, S., Juanes, J.A., 2016. Average vs. extreme salinity conditions: do they equally affect the distribution of macroinvertebrates in estuarine environments? *Limnol. Oceanogr.* 61, 984–1000. <http://dx.doi.org/10.1002/lno.10267>.
- Gambi, M.C., Barbieri, F., Bianchi, C.N., 2009. New record of the alien seagrass Halophila stipulacea (Hydrocharitaceae) in the western Mediterranean: a further clue to changing Mediterranean Sea biogeography. *Mar. Biodivers. Rec.* 2, e84. <http://dx.doi.org/10.1017/S175526720900058X>.
- GBIF, 2013. GBIF Backbone Taxonomy, 2013-07-01 [WWW Document]. URL: <http://www.gbif.org/species/5328663>. (Accessed 23 June 2015). on 2016-01-27.
- Georgioui, S., Mantziafou, A., Sofianos, S., Gertman, I., Özsoy, E., Somot, S., Vervatis, V., 2015. Climate variability and deep water mass characteristics in the Aegean Sea. *Atmos. Res.* 152, 146–158. <http://dx.doi.org/10.1016/j.atmosres.2014.07.023>.
- Gevrey, M., Dimopoulos, I., Lek, S., 2003. Review and comparison of methods to study the contribution of variables in artificial neural network models. *Ecol. Modell.* 160, 249–264. [http://dx.doi.org/10.1016/S0304-3800\(02\)00257-0](http://dx.doi.org/10.1016/S0304-3800(02)00257-0).
- Giaccone, G., Sortino, M., 1974. Significato biogeografico della vegetazione marina della Sicilia e delle isole minori nell'area del Mare Mediterraneo. *Boll. Stud. Inf. del Giard. Colon. Palermo* 26, 130–146.
- Goldenberg Vilar, A., Van Dam, H., Vonk, J.A., Van Der Geest, H.G., Admiraal, W., 2014. Typology of diatom communities in the Dutch delta: recognizing patterns of environmental drivers in nutrient rich ditches. *Ecol. Indic.* 45, 561–569. <http://dx.doi.org/10.1016/j.ecolind.2014.05.016>.
- Green, E.P., Short, F.T., 2003. World Atlas of Seagrasses. UNEP-WCMC by the University of California Press. UNEP World Conservation Monitoring Centre, Berkeley, USA. <http://dx.doi.org/10.1515/BOT.2004.029>.
- Gregg, E.J., Ahrens, A.L., Ian Perry, R., 2012. Reconciling classifications of ecologically and biologically significant areas in the world's oceans. *Mar. Policy* 36, 716–726. <http://dx.doi.org/10.1016/j.marpol.2011.10.009>.
- Gregg, E.J., Bodtker, K.M., 2006. Adaptive Classification of Marine Ecosystems: Identifying Biologically Meaningful Regions in the Marine Environment. Fisheries Bethesda, Vancouver, Canada. <http://dx.doi.org/10.1139/xxxx>.
- Hartigan, J.A., Wong, M.A., 1979. Algorithm AS 136: A K-Means clustering algorithm. *Appl. Stat.* 28, 100. <http://dx.doi.org/10.2307/2346830>.
- Holcer, D., Lazar, B., Mackelworth, P., Fortuna, C.M., 2013. Rare or just unknown? The occurrence of the giant devil ray (Mobula mobular) in the Adriatic Sea. *J. Appl. Ichthyol.* 29, 139–144. <http://dx.doi.org/10.1111/jai.12034>.
- Howell, K.L., 2010. A benthic classification system to aid in the implementation of marine protected area networks in the deep/high seas of the NE Atlantic. *Biol. Conserv.* 143, 1041–1056. <http://dx.doi.org/10.1016/j.biocon.2010.02.001>.
- Huang, H., Bin, C., Jinlan, L., 2015. The marine spatial classification and the identification of priority conservation areas (PCAs) for marine biodiversity conservation — a case study of the offshore China. *Ocean. Coast. Manag.* 116, 224–236. <http://dx.doi.org/10.1016/j.ocecoaman.2015.06.027>.
- Infantes, E., Orfila, A., Bouma, T.J., Simarro, G., Terrados, J., 2011. Posidonia oceanica and Cymodocea nodosa seedling tolerance to wave exposure. *Limnol. Oceanogr.* 56, 2223–2232. <http://dx.doi.org/10.4319/lno.2011.56.6.2223>.
- IUCN, 2015. The IUCN Red List of Threatened Species [WWW Document]. URL, Version 2015-3. <http://www.iucnredlist.org/>. (Accessed 16 September 2015).
- Jensen, M.M., Denny, M.W., 2015. Experimental determination of the hydrodynamic forces responsible for wave impact events. *J. Exp. Mar. Bio. Ecol.* 469, 123–130. <http://dx.doi.org/10.1016/j.jembe.2015.04.013>.
- Juanes, J.A., Puente, A., Ramos, E., 2016. A global approach to hierarchical classification of coastal waters at different spatial scales: the NEA case. *J. Mar. Biol. Assoc. U. K.* 1–12. <http://dx.doi.org/10.1017/S0025315416000801>.
- Kiviluoto, K., 1996. Topology preservation in self organizing maps. In: Proceedings of the International Conference on Neural Networks (ICNN'96), vol. 1. IEEE Neural Networks Council, Piscataway, New Jersey, USA, pp. 294–299.
- Kleisner, K.M., Coll, M., Lynam, C.P., Bundy, A., Shannon, L., Shin, Y.-J., Boldt, J.L., Maria, F.B., Diallo, I., Fox, C., Gascuel, D., Heymans, J.J., Juan Jordà, M.J., Jouffre, D., Large, S.I., Marshall, K.N., Ojaveer, H., Piroddi, C., Tam, J., Torres, M.A., Travers-Trolet, M., Tsagarakis, K., van der Meer, G.L., Zador, S., 2015. Evaluating changes in marine communities that provide ecosystem services through comparative assessments of community indicators. *Ecosyst. Serv.* 1–17. <http://dx.doi.org/10.1016/j.ecoser.2015.02.002>.
- Kohonen, T., 2001. Self-organizing Maps. Berlin.
- Kohonen, T., 1998. The self-organizing map. *Neurocomputing* 21, 1–6. [http://dx.doi.org/10.1016/S0925-2312\(98\)00030-7](http://dx.doi.org/10.1016/S0925-2312(98)00030-7).
- Lacoue-Labarthe, T., Nunes, P.A.L.D., Ziveri, P., Cinar, M., Gazeau, F., Hall-Spencer, J.M., Hilmi, N., Moschella, P., Safa, A., Sauzade, D., Turley, C., 2016. Impacts of ocean acidification in a warming Mediterranean Sea: an overview. *Reg. Stud. Mar. Sci.* 5, 1–11. <http://dx.doi.org/10.1016/j.rsma.2015.12.005>.
- Larkum, A., Orth, R.J., Duarte, C.M., 2006. Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht (The Netherlands).
- Last, P.R., Lyne, V.D., Williams, A., Davies, C.R., Butler, A.J., Yearsley, G.K., 2010. A hierarchical framework for classifying seabed biodiversity with application to planning and managing Australia's marine biological resources. *Biol. Conserv.* 143, 1675–1686. <http://dx.doi.org/10.1016/j.biocon.2010.04.008>.
- Lee, K.S., Park, S.R., Kim, Y.K., 2007. Effects of irradiance, temperature, and nutrients on growth dynamics of seagrasses: a review. *J. Exp. Mar. Bio. Ecol.* 350, 144–175. <http://dx.doi.org/10.1016/j.jembe.2007.06.016>.
- Levitus, S., Antonov, J.I., Baranova, O.K., Boyer, T.P., Coleman, C.L., Garcia, H.E., Grodsky, A.I., Johnson, D.R., Locarnini, R.A., Mishonov, A.V., Reagan, J.R., Sazama, C.L., Seidov, D., Smolyar, I., Yarosh, E.S., Zweng, M.M., 2013. The World Ocean database. *Data Sci. J.* 12, WDS229–WDS234. <http://dx.doi.org/10.2481/dsj.WDS-041>.
- Lipkin, Y., 1975. Halophila stipulacea, a review of a successful immigration. *Aquat. Bot.* 1, 203–215. [http://dx.doi.org/10.1016/0304-3770\(75\)90023-6](http://dx.doi.org/10.1016/0304-3770(75)90023-6).
- Luque, Á.A., Templado González, J., 2004. Praderas y bosques marinos de Andalucía. *Consejería de Medio Ambiente, Junta de Andalucía, Sevilla*.
- Makino, A., Klein, C.J., Possingham, H.P., Yamano, H., Yara, Y., Ariga, T., Matsuhashi, K., Beger, M., 2015. The effect of applying alternate IPCC climate scenarios to Marine Reserve design for range changing species. *Conserv. Lett.* 8, 320–328. <http://dx.doi.org/10.1111/conl.12147>.
- Marbà, N., Jordà, G., Agustí, S., Girard, C., Duarte, C.M., 2015. Footprints of climate change on Mediterranean Sea biota. *Front. Mar. Sci.* 2, 1–11. <http://dx.doi.org/10.3389/fmars.2015.00056>.
- Marbà, N., Krause-Jensen, D., Alcoverro, T., Birk, S., Pedersen, A., Neto, J.M., Orfanidis, S., Garmendia, J.M., Muxika, I., Borja, A., Dencheva, K., Duarte, C.M., 2013. Diversity of European seagrass indicators: patterns within and across regions. *Hydrobiologia* 704, 265–278. <http://dx.doi.org/10.1007/s10750-012-1403-7>.
- Marín-Guirao, L., Sandoval-Gil, J.M., Ruíz, J.M., Sánchez-Lizaso, J.L., 2011. Photosynthesis, growth and survival of the Mediterranean seagrass Posidonia oceanica in response to simulated salinity increases in a laboratory mesocosm system. *Estuar. Coast. Shelf Sci.* 92, 286–296. <http://dx.doi.org/10.1016/j.ecss.2011.01.003>.
- Micheli, C., Paganin, P., Peirano, A., Caye, G., Meinesz, A., Bianchi, C.N., 2005. Genetic variability of Posidonia oceanica (L.) Delile in relation to local factors and biogeographic patterns. *Aquat. Bot.* 82, 210–221. <http://dx.doi.org/10.1016/j.aquabot.2005.03.002>.
- Millot, C., 1999. Circulation in the western mediterranean sea. *J. Mar. Syst.* 20, 423–442.
- Muller-Karger, F., Andréfouët, S., Varela, R., Thunell, R., 2005. The Color of the Coastal Ocean and Applications in the Solution of Research and Management Problems, in: Remote Sensing of Coastal Aquatic Environments - Technologies, Techniques and Applications. Springer, Dordrecht (The Netherlands), pp. 101–127.
- Nejrup, L.B., Pedersen, M.F., 2008. Effects of salinity and water temperature on the ecological performance of Zostera marina. *Aquat. Bot.* 88, 239–246. <http://dx.doi.org/10.1016/j.aquabot.2007.10.006>.
- Nieblas, A.E., Drushka, K., Reygondeau, G., Rossi, V., Demarcq, H., Dubroca, L., Bonhommeau, S., Madron, X.D. de, Guieu, C., Sempéré, R., Conan, P., Cossa, D., Fraschetti, S., Micheli, F., Levin, N., Giakoumi, S., Katsanevakis, S., Abdulla, A., Portman, M., Notarbartolo-di-Sciara, G., Agardy, T., Katsanevakis, S., Possingham, H., Abdulla, A., Gomei, M., Hyrenbach, D., Notarbartolo-di-Sciara, G., Agardy, T., Bianchi, C., Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Lasram, F., D'Ortenzio, F., D'Alcalá, M.L., Lejeune, C., Chevaldonne, P., Pergent-Martini, C., Boudouresque, C., Perez, T., Halpern, B., Walbridge, S., Selkoe, K., Kappel, C., Micheli, F., Spalding, M., Fox, H., Allen, G., Davidson, N., Ferdaña, Z., Rice, J., Gjerde, K., Ardron, J., Arico, S., Cresswell, I., Coll, M., Cury, P., Azzurro, E., Bariche, M., Bayadas, G., Edgar, G., Moverly, J., Barrett, N., Peters, D., Reed, C., Reygondeau, G., Longhurst, A., Martinez, E., Beauprand, G., Antoine, D., Kavanaugh, M., Hales, B., Saraceno, M., Spitz, Y., White, A., Giakoumi, S., Sini, M., Gerovasileiou, V., Mazor, T., Behr, J., Millot, C., Millot, C., Robinson, A., Malanotte-Rizzoli, P., Hecht, A., Michelato, A., Roether, W., Sherman, K., Sissenwine, M., Christensen, V., Duda, A., Hempel, G., Lehahn, Y., D'Ovidio, E., Levy, M., Heifetz, E., Rossi, V., Lopez, C., Sudre, J., Hernandez-Garcia, E., Garcon, V., Rossi, V., Ser-Giacomi, E., López, C., Hernández-García, E.,

- Reygondeau, G., Irissou, J.O., Guieu, C., Gasparini, S., Ayata, S., Sydeman, W., Thompson, S., García-Reyes, M., Kahru, M., Peterson, W., Canny, J., Nieto, K., Demarcq, H., McClatchie, S., D'Ovidio, F., Fernández, V., Hernández-García, E., López, C., Tew-Kai, E., Rossi, V., Sudre, J., Weimerskirch, H., López, C., Okubo, A., Weiss, J., Henson, S., Thomas, A., Hartigan, J., Wong, M., Oliver, M., Glenn, S., Kohut, J., Irwin, A., Schofield, O., Beaugrand, G., Ibanez, F., Josey, S., Somot, S., Tsimplis, M., Papadopoulos, V., Josey, S., Bartzokas, A., Somot, S., Ruiz, S., Fernández, V., Dietrich, D., Haney, R., Tintoré, J., Larnicol, G., Ayoub, N., Traon, P. Le, Malanotte-Rizzoli, P., Manca, B., D'Alcalá, M., Theocharis, A., Bergamasco, A., Pinardi, N., Masetti, E., Longhurst, A., Sathyendranath, S., Platt, T., Caverhill, C., Chase, J., Leibold, M., Zavatarelli, M., Mellor, G., Hernández-Carrasco, I., López, C., Hernández-García, E., Turiel, A., D'Ovidio, F., Isern-Fontanet, J., López, C., Hernández-García, E., García-Ladona, E., Cayula, J., Cornillon, P., Hyrenbach, K., Forney, K., Dayton, P., 2014. Defining mediterranean and black sea biogeochemical subprovinces and synthetic ocean indicators using mesoscale oceanographic features. *PLoS One* 9, e111251. <http://dx.doi.org/10.1371/journal.pone.0111251>.
- Notarbartolo di Scia, G., Agardy, T., 2010a. *The Mediterranean Sea Biodiversity: State of the Ecosystems, Pressures, Impacts and Future Priorities*.
- Notarbartolo di Scia, G., Agardy, T., 2010b. Overview of Scientific Findings and Criteria Relevant to Identifying SPAMIs in the Mediterranean Open Seas, Including the Deep Sea. <http://dx.doi.org/10.1002/9780470670590.wbeog931>.
- OB.DAAC, 2013. Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Ocean Color Data [WWW Document]. URL <http://oceancolor.gsfc.nasa.gov/cms/dataaccess>. (Accessed 15 December 2013).
- OBIS, 2015. The OBIS Web Portal Search Interface [WWW Document]. URL <http://iobis.org/mapper/>. (Accessed 23 June 2015).
- Olsen, Y.S., Sánchez-Camacho, M., Marbà, N., Duarte, C.M., 2012. Mediterranean seagrass growth and demography responses to experimental warming. *Estuaries Coasts* 35, 1205–1213. <http://dx.doi.org/10.1007/s12237-012-9521-z>.
- Ondiviela, B., Alcántara, M.A., Fernández, L., 2005. Contribución al conocimiento de las comunidades de *Zostera* spp. del Cantábrico: la bahía de Santander y las marismas de Santoña. *Lucostella*, pp. 55–67.
- Ondiviela, B., Losada, I.J., Lara, J.L., Maza, M., Galván, C., Bouma, T.J., van Belzen, J., 2014. The role of seagrasses in coastal protection in a changing climate. *Coast. Eng.* 87, 158–168. <http://dx.doi.org/10.1016/j.coastaleng.2013.11.005>.
- Otero, M., Cebrían, E., Francour, P., Galil, B., Savini, D., 2013. Monitoring Marine Invasive Species in Mediterranean Marine Protected Areas (MPAs): a Strategy and Practical Guide for Managers. IUCN, Malaga, Spain, p. 136.
- Panigada, S., Zanardelli, M., MacKenzie, M., Donovan, C., Mélin, F., Hammond, P.S., 2008. Modelling habitat preferences for fin whales and striped dolphins in the Pelagos Sanctuary (Western Mediterranean Sea) with physiographic and remote sensing variables. *Remote Sens. Environ.* 112, 3400–3412. <http://dx.doi.org/10.1016/j.rse.2007.11.017>.
- Peralta, G., 2000. Estudios sobre el crecimiento en *Zostera noltii* Hornem.: Dinámica estacional y aspectos ecofisiológicos. University of Cádiz.
- Perez, J., Menendez, M., Losada, I.J., 2017. GOW2: a global wave hindcast for coastal applications. *Coast. Eng.* 124, 1–11. <http://dx.doi.org/10.1016/j.coastaleng.2017.03.005>.
- Pérez, M., Romero, J., 1994. Growth dynamics, production, and nutrient status of the seagrass *Cymodocea nodosa* in a mediterranean semi-estuarine environment. *Mar. Ecol.* 15, 51–64. <http://dx.doi.org/10.1111/j.1439-0485.1994.tb00041.x>.
- Poulos, S.E., Collins, M.B., 1997. Seasonal variability in sea surface oceanographic conditions in the Aegean Sea (Eastern Mediterranean): an overview. *J. Mar. Syst.* 13, 225–244.
- Puente, A., Guinda, X., Juanes, J.A., Ramos, E., Echavarrri-Erasun, B., de la Hoz, C.F., Degraer, S., Kerckhof, F., Rousou, M., Orav-Kotta, H., Kotta, J., Jourde, J., Pedrotti, M.L., Leclerc, J.-C., Simon, N., Bachelet, G., Arvanitidis, C., Pavloudi, C., Faulwetter, S., Crowe, T., Coughlan, J., Benedetti-Cecchi, L., Dal Bello, M., Magni, P., Como, S., Coppa, S., De Lucia, G., Rugins, T., Jankowska, E., Weslawski, J.M., Warzocha, J., Silva, T., Ribeiro, P., Matos, V., Sousa-Pinto, I., Troncoso, J.S., Peleg, O., Rilov, G., Espinosa, F., Péres Ruzafa, A., Frost, M., Hummel, H., van Avesaath, P., 2017. The role of physical variables in biodiversity patterns of intertidal macroalgae along European coasts. *J. Mar. Biol. Assoc. U.K.* 97, 549–560. <http://dx.doi.org/10.1017/S0025315416001673>.
- Ramos, E., Díaz de Terán, J.R., Puente, A., Juanes, J.A., 2016a. The role of geomorphology in the distribution of intertidal rocky macroalgae in the NE Atlantic region. *Estuar. Coast. Shelf Sci.* 179, 90–98. <http://dx.doi.org/10.1016/j.jecss.2015.10.007>.
- Ramos, E., Juanes, J.A., Galván, C., Neto, J.M., Melo, R., Pedersen, A., Scanlan, C., Wilkes, R., van den Bergh, E., Blomqvist, M., Karup, H.P., Heiber, W., Reitsma, J.M., Ximenes, M.C., Silió, A., Méndez, F., González, B., 2012. Coastal waters classification based on physical attributes along the NE Atlantic region. An approach for rocky macroalgae potential distribution. *Estuar. Coast. Shelf Sci.* 112, 105–114. <http://dx.doi.org/10.1016/j.jecss.2011.11.041>.
- Ramos, E., Puente, A., Guinda, X., Juanes, J.A., 2016b. A hierarchical classification system along the NE Atlantic coast: focusing on the local scale (Cantabria, N Spain). *Eur. J. Phycol.* <http://dx.doi.org/10.1016/j.jecss.2016.2014.1003216>.
- Ramos, E., Puente, A., Juanes, J.A., 2016c. An ecological classification of rocky shores at a regional scale: a predictive tool for management of conservation values. *Mar. Ecol.* 37, 311–328. <http://dx.doi.org/10.1111/maec.12280>.
- Ramos, E., Puente, A., Juanes, J.A., Neto, J.M., Pedersen, A., Bartsch, I., Scanlan, C., Wilkes, R., Van den Bergh, E., Ar Gall, E., Melo, R., 2014. Biological validation of physical coastal waters classification along the NE Atlantic region based on rocky macroalgae distribution. *Estuar. Coast. Shelf Sci.* 147, 103–112. <http://dx.doi.org/10.1016/j.jecss.2014.05.036>.
- Reguero, B.G., Menéndez, M., Méndez, F.J., Mínguez, R., Losada, I.J., 2012. A Global Ocean Wave (GOW) calibrated reanalysis from 1948 onwards. *Coast. Eng.* 65, 38–55. <http://dx.doi.org/10.1016/j.coastaleng.2012.03.003>.
- Reygondeau, G., Guieu, C., Benedetti, F., Irissou, J.O., Ayata, S.D., Gasparini, S., Koubbi, P., 2017. Biogeochemical regions of the Mediterranean Sea: an objective multidimensional and multivariate environmental approach. *Prog. Oceanogr.* 151, 138–148. <http://dx.doi.org/10.1016/j.pcean.2016.11.001>.
- Riis, T., Olesen, B., Clayton, J.S., Lambertini, C., Brix, H., Sorrell, B.K., 2012. Growth and morphology in relation to temperature and light availability during the establishment of three invasive aquatic plant species. *Aquat. Bot.* 102, 56–64. <http://dx.doi.org/10.1016/j.aquabot.2012.05.002>.
- Roberts-Jones, J., Fiedler, E.K., Martin, M.J., 2012. Daily, global, high-resolution SST and sea ice reanalysis for 1985–2007 using the OSTIA system. *J. Clim.* 25, 6215–6232. <http://dx.doi.org/10.1175/JCLI-D-11-00648.1>.
- Roca, G., Alcoverro, T., Krause-Jensen, D., Balsby, T.J.S., Van Katwijk, M.M., Marbà, N., Santos, R., Arthur, R., Mascaró, O., Fernández-Torquemada, Y., Pérez, M., Duarte, C.M., Romero, J., 2016. Response of seagrass indicators to shifts in environmental stressors: a global review and management synthesis. *Ecol. Indic.* 63, 310–323. <http://dx.doi.org/10.1016/j.ecolind.2015.12.007>.
- Rodríguez-Rodríguez, D., Rodríguez, J., Abdul Malak, D., Nastasi, A., Hernández, P., 2016. Marine protected areas and fisheries restricted areas in the Mediterranean: assessing “actual” marine biodiversity protection coverage at multiple scales. *Mar. Policy* 64, 24–30. <http://dx.doi.org/10.1016/j.marpol.2015.11.006>.
- Rodríguez, J., 1982. Oceanografía del Mar Mediterráneo. Pirámide.
- Roff, J.C., Taylor, M.E., 2000. National frameworks for marine conservation - a hierarchical geophysical approach. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 10, 209–223.
- Rossi, V., Ser-Giacomi, E., López, C., Hernández-García, E., 2014. Hydrodynamic provinces and oceanic connectivity from a transport network help designing marine reserves. *Geophys. Res. Lett.* 41, 2883–2891. <http://dx.doi.org/10.1002/2014GL059540>.
- Sánchez-Lizaso, J.L., Romero, J., Ruiz, J., Gacia, E., Buceta, J.L., Invers, O., Fernández Torquemada, Y., Mas, J., Ruiz-Mateo, A., Manzanera, M., 2008. Salinity tolerance of the Mediterranean seagrass *Posidonia oceanica*: recommendations to minimize the impact of brine discharges from desalination plants. *Desalination* 221, 602–607. <http://dx.doi.org/10.1016/j.desal.2007.01.119>.
- Sánchez Lisazo, J.L., 1993. Estudio de la pradera de *Posidonia oceanica* (L.) Delile de la reserva marina de Tabarca (Alicante): Fenología y producción primaria. *Dep. Ciències Ambient. i Recur. Nat.* 121.
- Sarda, F., Calafat, A., Flexas, M.M., Tselepidis, A., Canals, M., Espino, M., Tursi, A., 2004. An introduction to Mediterranean deep-sea biology. *Sci. Mar.* 68, 7–38. <http://dx.doi.org/10.3989/scimar.2004.68s37>.
- Seabra, R., Wethey, D.S., Lima, F.P., Campo, R., 2015. Understanding complex biogeochemical responses to climate change. *Sci. Rep.* 12930 <http://dx.doi.org/10.1038/srep12930>.
- Short, F.T., Carruthers, T., Dennison, W., Waycott, M., 2007. Global seagrass distribution and diversity: a bioregional model. *J. Exp. Mar. Biol. Ecol.* 350, 3–20. <http://dx.doi.org/10.1016/j.jembe.2007.06.012>.
- Short, F.T., Carruthers, T.J.R., Waycott, M., Kendrick, G.A., Fourqurean, J.W., Callabine, A., Kenworthy, W.J., Dennison, W.C., 2010a. *Zostera Marina*. <http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T153538A4516675.en> [WWW Document]. IUCN Red List Threat. Species. URL. (Accessed 10 November 2015).
- Short, F.T., Carruthers, T.J.R., Waycott, M., Kendrick, G.A., Fourqurean, J.W., Callabine, A., Kenworthy, W.J., Dennison, W.C., 2010b. *Zostera noltii*. <http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T173361A6999224.en> [WWW Document]. IUCN Red List Threat. Species. URL. (Accessed 10 November 2015).
- Short, F.T., Carruthers, T.J.R., Waycott, M., Kendrick, G.A., Fourqurean, J.W., Callabine, A., Kenworthy, W.J., Dennison, W.C., 2010c. *Halophila Stipulacea* [WWW Document]. IUCN Red List Threat. Species.
- Sims, D.W., Southall, E.J., Richardson, A.J., Reid, P.C., Metcalfe, J.D., 2003. Foraging and migratory behaviour of basking sharks over seasonal scales: no evidence for winter hibernation. *Mar. Ecol. Prog. Ser.* 248, 187–196. <http://dx.doi.org/10.3354/meps248187>.
- Sims, D.W., Southall, E.J., Tarling, G.A., Metcalfe, J.D., 2005. Habitat-specific normal and reverse diel vertical migration in the plankton-feeding basking shark. *J. Anim. Ecol.* 74, 755–761. <http://dx.doi.org/10.1111/j.1365-2656.2005.00971.x>.
- Spalding, M.D., Fox, H.E., Allen, G.R., Davidson, N., Ferdaña, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A., Lourie, S.A., Martin, K.D., Mcmanus, E., Molnar, J., Recchia, C.A., Robertson, J., 2007. Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *Bioscience* 57, 573–583. <http://dx.doi.org/10.1641/B570707>.
- Stojković, M., Milošević, D., Simić, S., Simić, V., 2014. Using a fish-based model to assess the ecological status of lotic systems in Serbia. *Water Resour. Manag.* 28, 4615–4629. <http://dx.doi.org/10.1007/s11269-014-0762-4>.
- Telesca, L., Belluscio, A., Criscoli, A., Ardizzone, G., Apostolaki, E.T., Fraschetti, S., Gristina, M., Knittweis, L., Martin, C.S., Pergent, G., Alagna, A., Badalamenti, F., Garofalo, G., Gerakaris, V., Louise Pace, M., Pergent-Martini, C., Salomidi, M., 2015. Seagrass meadows (*Posidonia oceanica*) distribution and trajectories of change. *Sci. Rep.* 5, 1–14. <http://dx.doi.org/10.1038/srep12505>.
- Templado González, J., 1995. Las comunidades de fanerógamas marinas en el Mediterráneo Occidental. In: *La Gestión de Los Espacios Marinos En El Mediterráneo Occidental: Actas de La VII Aula de Ecología*. Almería, pp. 29–37.
- Tomás, A., Méndez, F.J., Losada, I.J., 2012. Bed Shear Stress during Sant Esteve's Storm (26th December 2008) along the Catalonia's Coast (NW Mediterranean).

- Touchette, B.W., 2007. Seagrass-salinity interactions: physiological mechanisms used by submersed marine angiosperms for a life at sea. *J. Exp. Mar. Bio. Ecol.* 350, 194–215. <http://dx.doi.org/10.1016/j.jembe.2007.05.037>.
- Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., Steininger, M., 2003. Remote sensing for biodiversity science and conservation. *Trends Ecol. Evol.* 18, 306–314. [http://dx.doi.org/10.1016/S0169-5347\(03\)00070-3](http://dx.doi.org/10.1016/S0169-5347(03)00070-3).
- UNEP-MAP-RAC/SPA, 1995. Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean.
- Unsworth, R.K.F., Collier, C.J., Waycott, M., McKenzie, L.J., Cullen-Unsworth, L.C., 2015. A framework for the resilience of seagrass ecosystems. *Mar. Pollut. Bull.* <http://dx.doi.org/10.1016/j.marpolbul.2015.08.016>.
- Valle, M., Chust, G., del Campo, A., Wisz, M.S., Olsen, S.M., Garmendia, J.M., Borja, Á., 2014. Projecting future distribution of the seagrass *Zostera noltii* under global warming and sea level rise. *Biol. Conserv.* 170, 74–85. <http://dx.doi.org/10.1016/j.biocon.2013.12.017>.
- Valle, M., van Katwijk, M.M., de Jong, D.J., Bouma, T.J., Schipper, A.M., Chust, G., Benito, B.M., Garmendia, J.M., Borja, Á., 2013. Comparing the performance of species distribution models of *Zostera marina*: implications for conservation. *J. Sea Res.* 83, 56–64. <http://dx.doi.org/10.1016/j.seares.2013.03.002>.
- Vesanto, J., Himberg, J., Alhoniemi, E., Parhankangas, J., 2000. SOM Toolbox for Matlab 5. Tech. Rep. A57 2, p. 59.
- Vuorinen, I., Hänninen, J., Rajasilta, M., Laine, P., Eklund, J., Montesino-Pouzols, F., Corona, F., Junker, K., Meier, H.E.M., Dippner, J.W., 2015. Scenario simulations of future salinity and ecological consequences in the Baltic Sea and adjacent North Sea areas—implications for environmental monitoring. *Ecol. Indic.* 50, 196–205. <http://dx.doi.org/10.1016/j.ecolind.2014.10.019>.
- Witze, A., 2017. Ocean ecosystems mapped in unprecedented 3D detail. *Nature* 541, 10–11.
- Worner, S., Eschen, R., Kenis, M., Paini, D., Saikkonen, K., Suiter, K., Venette, R.C., 2015. Detecting and interpreting patterns within regional pest species assemblages using self-organizing maps and other clustering methods. In: Venette, R.C. (Ed.), *Pest Risk Modelling and Mapping for Invasive Alien Species*, p. 97. Boston, USA. www.cabi.org.
- Zacharias, M.A., Roff, J.C., 2000. A hierarchical ecological approach to conserving marine biodiversity. *Conserv. Biol.* 14, 1327–1334. <http://dx.doi.org/10.1046/j.1523-1739.2000.99191.x>.